Dust Dynamics of 9P/Tempel 1

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Abstract

On February 15, 2011 the stardust spacecraft performed a flyby of the comet 9P/Tempel 1 (Tempel 1). During this flyby, the Dust Flux Monitor Instrument (DFMI) measured the mass distribution of dust particles within the comet's coma. Instead of a gaussian distribution of mass, researchers found that the dust particles were concentrated in small clouds separated by large regions of empty space. This research project will investigate possible factors that would lead to such a distribution of dust particles. Our first objective is to model the fragmentation of dust particles as they leave the surface of Tempel 1. We believe that fragmentation of larger particles could result in the clouds of dust particles observed by the stardust spacecraft [2]. Our second aim is to model the distribution of these dust clouds around Tempel 1. In order to evaluate our results, we will compare numerical simulations based on the models with data from the Stardust NExT mission. These methods will provide key insights to the properties and dynamics of dust in the coma of Tempel 1. The results of numerical models of dust fragmentation will refine our understanding of cometary dust and further our ability to simulate dust dynamics.

1 Introduction

During the Stardust NExT mission, the DFMI recorded the masses of particles colliding with the spacecraft. Sensors based on polyvinylidene fluoride (PVDF) films and on acoustic detectors (AC) were contained in the DFMI [2]. These sensors were able to detect particles ranging from 10^{-15} to 10^{-6} kg [4].The spacecraft flew in a linear trajectory, with a close approach distance of 178 km and a relative velocity

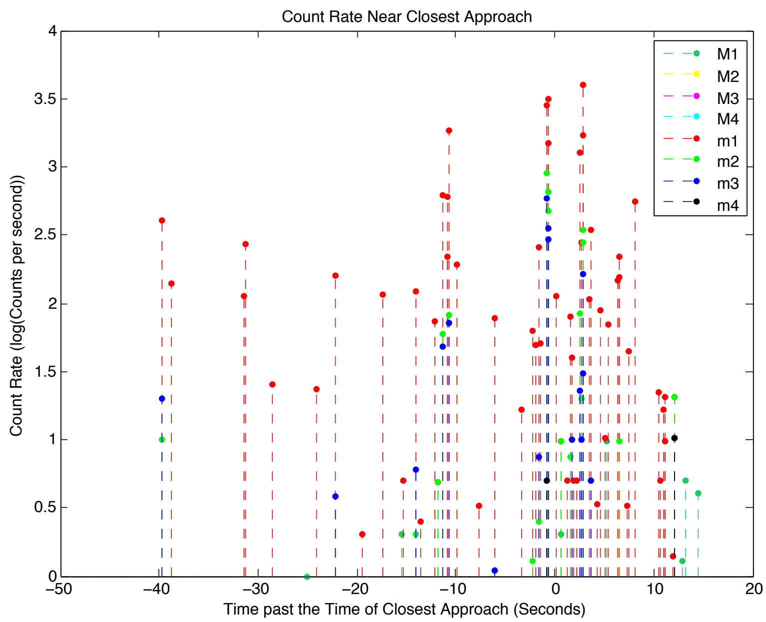

Figure 1: This plot illustrates the number of particles detected per second on the Y-axis, corresponding to each mass bin (M1-m4), on a logarithmic scale. On the X-axis the time past the time of closest approach is shown on a linear scale.

of 10.9 km/s [1]. Clouds of particles ranging up to 1000 particles over a distance of a few kilometers were also detected, separated by large regions without any impacts [2]. These findings paralleled similar observations of 81P/Wild 2 from the earlier Stardust mission. These data contradict the previous expectations of a relatively smooth gaussian distribution of particle impacts near close approach (figure 1). The aim of our research will be to explain these contradictions with a sound physical model of particle fragmentation. As ice sublimates on the nucleus surface, dust particles are released from the comet [3]. As these particles move away from the nucleus, discrete dust clouds in the coma could be a result of fragmenting, or, breaking apart in a particular manner. Each particle initially released from the nucleus would result in a single discrete cloud of fragmented particles.

2 Methods

We plan on using several computational techniques to describe the dust cloud phenomena observed on Tempel 1. Using MATLAB, we will implement various models of particle fragmentation, for particles being ejected from the surface of Tempel 1. We will begin with a model that will simulate fragmentation by allowing each particle to break apart into a discrete number of sub-particles on random time intervals. The mass of the system will be conserved, and each sub-particle will have identical mass. The number of assumptions that need to be made in order to simplify the computational difficulties of the simulation will limit the accuracy of our initial model. As we build upon the algorithm, our aim will be to cut down on the number of assumptions being made. After obtaining results from this approach, we will make necessary adjustments and refinements to our model. Each model will be constructed using Monte Carlo simulations as a means of reconstructing the dynamics of the dust particles. Specifically, we will use the random behavior of a fragmenting particle to simulate possible dust cloud distributions. We will then measure our computed results against the observed data supplied by the Small Bodies Node of the Planetary Data System archive. These comparisons will inform us which model most accurately describes the observed phenomena.

Once we have obtained an accurate model describing the fragmentation of particles, we will proceed to simulate the distribution of clouds around Tempel 1. This will include the creation of a geometric coordinate system around the comet, and a method for describing the frequency and distribution of particles being ejected from the surface. This model will again be implemented using code in MATLAB.

One of the largest obstacles faced in building these models is the limitations of the data. Since we only have data for the mass density of particles as a function of the spacecraft's path, it will be difficult to build a 3-dimensional model of particle distributions. In order to compensate for this limitation, we will need to consider several different paths that the spacecraft could have taken through each dust cloud.

3 Data

The data from the Stardust NExT mission will be integral to this project. We will be primarily concerned with the Dust Flux Monitor Instrument. This instrument contained two detectors: a polyvinylidene fluoride (PVDF) dust sensor unit (SU), and a dual acoustic sensor system (DASS). The PVDF sensor detects particles with mass less than 10^{-4} grams. The DASS uses two quartz piezoelectric accelerometers to measure the flux of particles with mass greater than 10^{-4} grams [1]. The DFMI data output that we will be concerned with is the number of particle impacts corresponding to eight different mass bins. Each bin represents a different range of particle masses. Figure 1, 2, and 3 illustrate the count rate for each of the bins. The following table shows the mass threshold for each bin in kilograms [2]

Bin		Mass Threshold (kg)
$m1$	$=$	2.6×10^{-15}
$m2$	$=$	3.2×10^{-14}
$m3$	$=$	3.6×10^{-13}
$m4$	$=$	5.3×10^{-11}
$M1$	$=$	1.2×10^{-11}
$M2$	$=$	2.5×10^{-10}
$M3$	$=$	2.0×10^{-9}
$M4$	$=$	2.2×10^{-8}

We can use the particle counter for each bin, together with the spacecraft position data, to reconstruct the spatial and mass distribution of the dust clouds. This data (ID: SDU-C/D-DFMI-2/3-NExT-TEMPEL1-V1.0) can be found using the Small Bodies Node of the Planetary Data System [1].

Once we have results for our numerical models, we will compare them to the data from Stardust NExT using statistical analysis. Our aim is to provide a model that has a strong correlation to the observations and will provide some insight to the origin of the dust clouds.

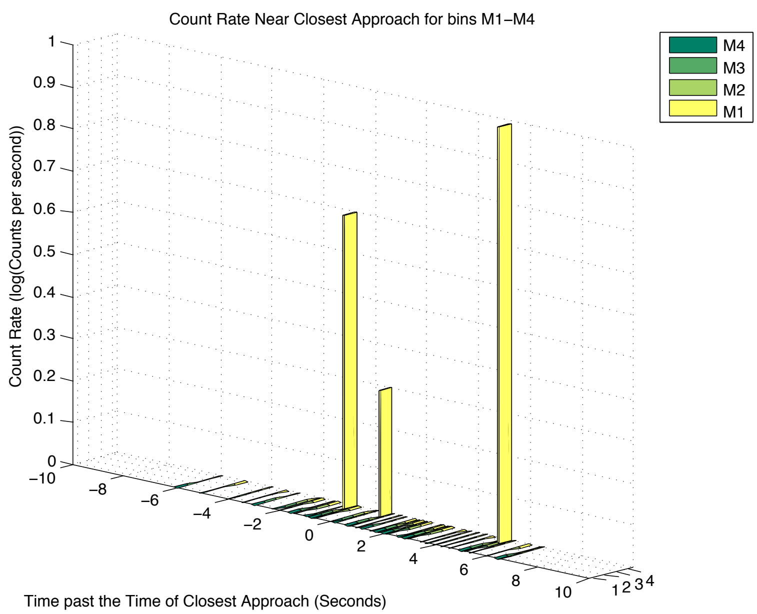

Figure 2: Number of particles detected per second near closest approach for bins M1-M4, on a logarithmic scale.

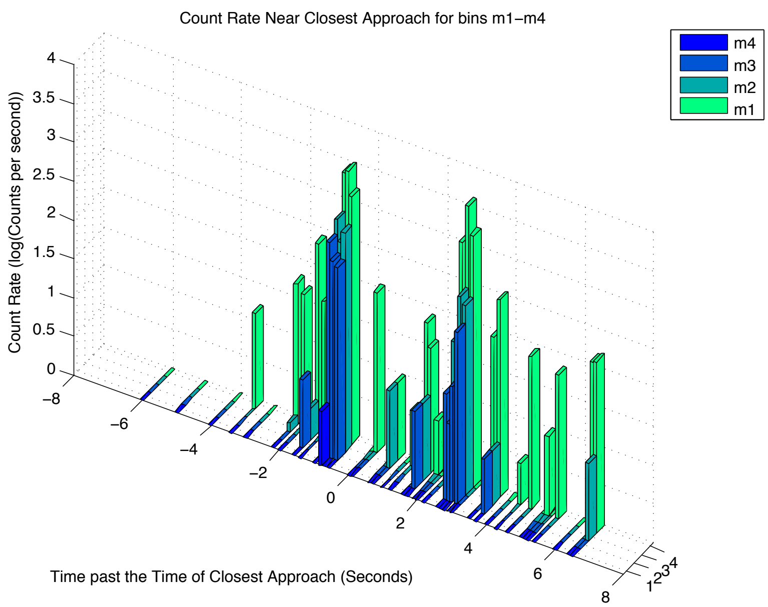

Figure 3: Number of particles detected per second near closest approach for bins m1-m4, on a logarithmic scale.

4 Research Plan

Our goal for this research project will be to answer several questions about the distribution of dust particles around Tempel 1. The primary question that we are looking to answer is which physical processes contribute to the formation and arrangement of dust clouds around the comet. In order to answer this question, we will use computational techniques to build models which incorporate the fundamental forces involved in particle fragmentation. We aim to simulate the fragmentation process by exploring parameters such as grain ejection velocity, grain lifetime, and fragmentation rates, as well as exploring processes such as solar radiation pressure and direction of emissions. Once we are able to find a model that agrees with observations, we will have a new insight to the physical processes behind the particle distribution of the coma of Tempel 1. Other questions that we aim to answer are: What time scale do these fragmentations occur? Can particle fragmentation alone provide an accurate model for the observations of Tempel 1? And what characteristics of the comet contribute to the observed distribution of dust clouds in the coma? These question will be answered with a similar analysis using computational implementations of various physical models in comparison with observed data.

References

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